

Fuel Oil Production from Pyrolysis of Waste Polyethylene Carry Bags

B. Prabha*, D. Ramesh and S. Sriramajayam

*Department of Renewable Energy Engineering,
Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University,
Coimbatore 641 003, Tamil Nadu, India*

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ABSTRACT

Waste plastics are a significant contributor to municipal and industrial wastes. Today, environmental pollution caused by waste plastics is a worldwide serious problem due to their continuous accumulation in the environment and inability to biodegrade for a long period. As a result, it is critical to find a safe way to dispose of waste plastics. Pyrolysis is one of the most effective methods for recovering useful products from waste plastics. The pyrolysis of waste polyethylene (PE) carry bags in a batch-type reactor is studied and discussed in this paper. Generally, the pyrolytic conversion of feedstocks produces solid, liquid, and gaseous products. Optimization experiments were carried out in a batch-type pyrolysis system at 400, 450, 500, and 550 °C to recover maximum fuel oil from plastic wastes. At 500 °C, the maximum fuel oil yielded as 59.3 percent in 42 minutes from waste PE carry bags. Whereas, the char and gas yields ranged from 6.6 and 34.1%, respectively. The calorific value of fuel oil was 40.8 MJ/kg. The presence of alkanes, alkenes, and alkynes functional groups in fuel oil was revealed by FT-IR analysis. These findings suggest that fuel oil derived from waste PE bags can be used as an alternative fuel.

Key words: Waste plastics, Polyethylene, Carry bags, Pyrolysis, Fuel oil

Introduction

Consumption of plastic products usage is increased in day to day, due to their flexibility and ease of manufacturing process. Furthermore, these products can satisfy the user's needs at a cheaper price as compared to products made of metal/glass. Among the plastics, thermoplastics are contributing a major share, which are mainly used for packaging, textile fibres and coatings. After their use, it is discarded as waste and a huge amount of waste is dumped into the environment. Based on their origins, plastic wastes are divided into municipal and industrial plastic wastes (Balakrishnan and Guria, 2007). As similar to other plastic wastes, thermoplastic poly-

mers also have a disposal problem. The plastic waste generated per day in India was ca.9,200 tonnes of (CPCB report, 2019). These plastic wastes pose a serious environmental challenge and they may take 400 to 1000 years for natural decomposition if microorganisms are used (Bell and Cave, 2011). Currently, landfilling, incineration and mechanical recycling methods are adopted for the disposal of plastic waste (Valerio, 2010). A higher amount of plastic waste is preferred to dispose of through landfills. Due to poor biodegradability, the explosion of greenhouse gases and high cost, landfilling is not preferred for plastic waste disposal (Garforth *et al.*, 2004). In the case of the incineration method, the burning of plastic waste generates

harmful gases and that cause air pollution (Sarker *et al.*, 2012). In the mechanical recycling process, the waste is separated from other materials and it is re-processed by melt extrusion. However, the deterrents of this method are expensive and energy-intensive (Mantia, 2002). Therefore, there is a need for a safe disposal method to convert these wastes into useful products.

Several thermal technologies can be utilized for the disposal and conversion of plastic waste such as pyrolysis, gasification and plasma process (Moustakas and Loizidou, 2010). Among these methods, pyrolysis is one of the preferable methods to obtain a wide variety of products and inexpensive methods (Patni *et al.*, 2013). Liquid fuel derived from plastic waste through pyrolysis has more scope and viable options for safe disposal (Kodera *et al.*, 2006). The fuel oil produced from plastic waste had high calorific value and properties that compete with petroleum distillates (Jan *et al.*, 2010). This paper examined the pyrolysis potential of thermal degradation of waste low-density plastic carry bags under different reaction temperatures and discussed the influential parameters for better liquid oil yield.

Materials and Methods

Characterization of plastic wastes

The proximate composition of waste PE carry bags such as volatile matter (ASTM D3175), ash content (ASTM D3174) and fixed carbon (ASTM D3172) were studied using ASTM procedures. The elemental composition of tested samples was determined using an elemental analyzer (Thermo Fisher, Flash 2000, USA) coupled with an autosampler and data processor by following ASTM D3176 procedure. The calorific value of samples was determined in a bomb calorimeter (M/s. Aditya, India) based on ASTM D 2015-77 procedure. The thermal property of plastic samples was analyzed using a thermogravimetric analyzer TGA Q50 (TA Instruments, USA). For this experiment, the waste LDPE carry bag sample (10 mg) was analyzed at a heating rate of $40\text{ }^{\circ}\text{C min}^{-1}$ under a nitrogen atmosphere (60 ml min^{-1}) from ambient temperature to $900\text{ }^{\circ}\text{C}$. From TGA experimental data, thermogravimetric (TG) and differential thermogravimetric (DTG) curves can be plotted using universal analysis software.

Lab-scale batch pyrolytic reactor

The laboratory-scale batch pyrolytic reactor consists

of a heating source, pyrolysis unit, and condenser. The muffle furnace was acting as a heating source to maintain a constant reaction temperature. The pyrolysis unit had two stainless steel cups to hold the test samples. A copper tube was used to connect the pyrolysis unit and condenser. During the experiment, a pyrolysis unit filled with a test sample was kept in the muffle furnace and nitrogen was purged in the unit to remove the air. Due to the inert environment and constant heating, the plastic sample undergoes thermal degradation and releases both condensable and non-condensable gases. Further, condensable gases are cooled with the help of a condenser unit, and the condensate collected is referred to as fuel oil.

Experimental procedure

A quantity of 10 g waste PE carry bag sample was filled in the cups of the pyrolysis unit and kept in the muffle furnace. The test sample was heated at a ramp of $15\text{ }^{\circ}\text{C min}^{-1}$ from ambient to reaction temperature. The test sample was subjected to a pyrolysis process under constant reaction temperature. The selected pyrolytic temperatures were $400\text{ }^{\circ}\text{C}$, $450\text{ }^{\circ}\text{C}$, $500\text{ }^{\circ}\text{C}$, and $550\text{ }^{\circ}\text{C}$ for the production of fuel oil from waste PE carry bags. The yields of fuel oil, solid residue, and gas were recorded. Time taken for complete conversion of waste PE carry bags used in the reactor into fuel oil can be referred to as residence time.

Characterization of fuel oil

ASTM procedures were adopted to study the important fuel properties of fuel oil like calorific value (ASTM D 2015-77), specific gravity (IS: 1448-1972), and kinematic viscosity (ASTM 445-72), and flash point (ASTM D93). The Fourier Transform Infra-Red (FT-IR) spectra were recorded by applying an attenuated total reflectance (ATR) crystal. FT-IR spectrophotometer (M/s. Bio-Rad, Jasco- 6800, Japan) was used to record the FT-IR spectra. The resolution of the equipment was 4 cm^{-1} , and the scan number was 32. The FT-IR spectrum in the significant ranges of $4000\text{ to }400\text{ cm}^{-1}$ was measured and recorded. Bruker software was used for further data analysis.

Results and Discussion

Properties of plastic wastes

The important physical and chemical properties of

waste PE carry bags were reported in Table 1. It was revealed that the volatile matter for a plastic waste sample has higher and lower ash content. This indicated that tested plastic wastes have a high potential to produce more amount of fuel oil under optimized process conditions. The hydrogen content of waste PE carry bags was similar to the results reported by Aboulkas *et al.*, (2010), and the hydrogen content of polyethylene wastes had 14.30 percent.

Table 1. Properties of waste PE carry bags

Properties	Waste PE carry bags
Calorific value, MJ/kg	40.12
Proximate composition	
Volatile matter, %	97.46
Ash content, %	2.37
Fixed carbon, %	0.17
Elemental composition	
Carbon, %	83.65
Hydrogen, %	14.10
Nitrogen, %	0.62
Sulphur, %	0.09
Oxygen, %	0.70

TGA of plastic wastes

The TGA of waste PE carry bags was carried out under non-isothermal conditions at a constant heating rate of 40 °C min⁻¹. The TG and DTG curves of tested samples at a heating rate of 40 °C min⁻¹ was shown in Figure 1.

TG curve shows smooth and only one inflection

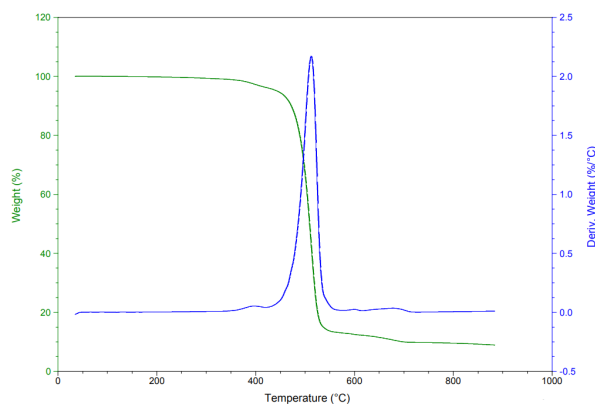


Fig. 1. TG and DTG curves of waste PE carry bags

found under inert atmosphere. DTG curve shows only one clear peak to represent the predominant pyrolysis reaction. The temperature observed for 5 and 95 percent conversion rates for tested samples

were 437 and 554 °C. The degradation temperature for the weight loss of 50 percent of the original sample (T50) was 512 °C for the plastic waste sample. The maximum weight loss was found to be 2.171 percent per °C. The analysis found that the percentage of solid residue left at 800 °C was 9.50 percent (by wt). The major portion of weight loss was found to be maximum at active pyrolysis zone temperature. The TGA experiment showed that the selection of reaction temperature has an important role in the thermal degradation of waste plastics. This result implies that the waste PE carry bags are suitable for the pyrolysis process to obtain valuable fuels like fuel oil or char.

Fuel oil production

The results obtained from pyrolysis of wastes PE carry bags using lab-scale batch pyrolytic reactor at various temperatures range (400 to 550 °C) to yield the different products *viz.*, fuel oil, solid residue and pyrolytic gas were presented in Table 2.

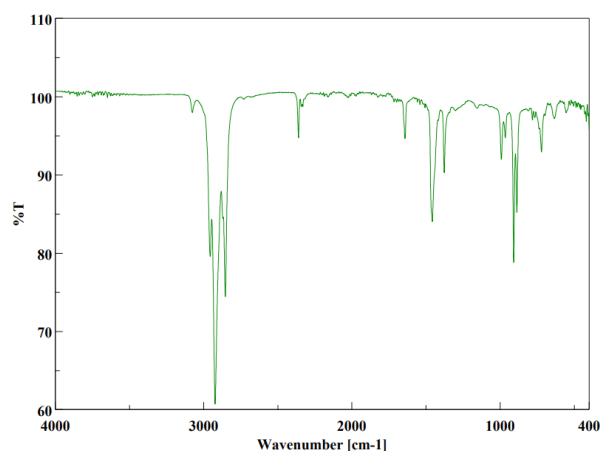
The yields of fuel oil, solid residue, and pyrolytic gas obtained from pyrolysis of wastes PE carry bags under different test conditions ranged from 37.6 to 59.3 percent, 4.7 to 11.7 percent 34.1 to 50.7 percent, respectively. The fuel oil recovery was very low at 400 °C, and a gradual increase in oil yield was observed up to 500 °C. With a further increase in reaction temperature, the oil yield was reduced, and solid residue and pyrolytic gas yields increased. The highest fuel oil yield was obtained from tested samples at 500 °C. The yields of fuel oil and non-condensable pyrolytic gas obtained under-tested reaction temperature were higher than that of solid residue. The reason may be due to the higher volatile content of plastic waste samples. Islam *et al.* (2010) reported that the higher volatile matter of feedstock with low ash content was a potential source for higher fuel oil yield. In the present study, the residence time observed for tested plastic waste samples ranged from 39 to 58 min. The residence time was decreased with an increase in reaction temperature and *vice versa*. The residence time was found to be higher at 400 °C and decreased with further increasing the temperature. Longer residence time promotes the conversion of plastics into hydrocarbons and non-condensable gas (Ludlow-Palafox and Chase, 2001). These results showed that the reaction temperature of the pyrolysis process has a significant effect on fuel oil yield and residence time.

Table 2. Pyrolytic end products from selected plastic wastes

Sample	Temperature, °C	Fuel oil, %	Solid residue, %	Pyrolytic gas, %	Residence time, min
Waste PE carry bags	400	37.6	11.7	50.7	58
	450	47.1	8.3	44.6	51
	500	59.3	6.6	34.1	42
	550	41.9	4.7	53.4	39

Properties of fuel oil

The calorific value of fuel oil (40.8 MJ/kg) was closer to petrol fuel. The specific gravity, kinematic viscosity and flash point of the fuel oil from PE wastes under optimized conditions were 0.824, 5.92 cSt and 46 °C, respectively. Desai and Galage (2015) reported the flash point of PE fuel oil as 41 °C. Ahmad *et al.* (2014) reported that the calorific value and flash point of petrol were 42.5 MJ/kg and 42 °C, respectively.

**Fig. 2.** FT-IR spectra of fuel oil**Table 3.** Assignment of FT-IR spectra functional group of fuel oil

Wave Number (cm ⁻¹)	Bond	Functional Group
2956.34	C-H stretch	Alkanes
2922.59	C-H stretch	Alkanes
2853.17	C-H stretch	Alkanes
2360.44	-C≡C- stretch	Alkanes
1642.09	-C=C- stretch	Alkanes
1457.92	C-H bend	Alkanes
1366.93	C-H rock	Alkanes
992.196	=C-H bend	Alkanes
908.308	=C-H bend	Alkanes
888.059	=C-H bend	Alkanes
721.247	C-H rock	Alkanes

FT-IR spectra

Fig. 2 and Table 3 show the FT-IR spectra and functional groups of fuel oil synthesized from waste PE carry bags. The presence of alkanes was determined by C-H stretching vibrations at a wave number of 2956.34, 2922.59 and 2853.17 cm⁻¹. Also, C-H bend and C-H rock vibrations at a wavenumber of 1457.92, 1366.93, and 721.247 cm⁻¹ indicate alkanes presence. The -C≡C- stretching vibrations at 2360.44 cm⁻¹ indicates the presence of alkynes. Alkenes were detected by -C=C- stretching and =C-H bend vibrations at a wave number of 1642.09, 992.196, 908.308, and 888.059 cm⁻¹.

Conclusion

Production of fuel oil from pyrolysis of waste PE carry bags was carried out in a laboratory-scale batch pyrolytic reactor and optimized the process parameters such as reaction temperature and residence time. The four different reaction temperatures (400-550°C) were tested for higher fuel oil yield from waste PE carry bags. The results show that the fuel oil yield was less at temperatures (400°C) and gradually increased upto 500°C. The increase in pyrolysis temperature reduces the residence time. The maximum yield of fuel oil (59.3 %) was obtained at 500°C for a residence time of 42 min. The properties of fuel oil were studied, and the calorific value was found to be 40.8 MJ/kg. The FT-IR spectra illustrate the presence of alkane and alkenes functional groups in fuel oil. Results showed that waste PE carry bags can be converted into fuel oil and offers a solution for safer disposal method for these wastes.

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